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The effects of heat treatment on some technological properties in Uludağ fir (*Abies bornmuellerinana* Mattf.) wood

Suleyman Korkut*

Faculty of Forestry, Department of Wood Mechanics and Technology, Abant Izzet Baysal University, 81620 Düzce, Turkey

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Abstract

Heat treatment is often applied to improve the dimensional stability of woods. In this study, the effect of heat treatment on some mechanical properties of Uludağ fir wood (*Abies bornmuellerinana* Mattf.) having industrially high usage potential and large plantations in Turkey was evaluated. Samples collected from Bolu Forest Enterprises, Turkey were subjected to heat treatment for varying temperatures and durations. Then, the treated and control samples were tested for some mechanical properties; compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain. The results indicated that treated samples had lower mechanical properties compared to the control samples. In addition, increase in temperature and durations decreased the mechanical properties.

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1. Introduction

Fir, having superior technological properties and having high usage potential, is an important species in lumber industry. It spreads over 627,143.4 ha, which consists of 3% of our total forest existence. Uludağ Fir wood (*Abies bornmuellerinana* Mattf.) naturally grown in Turkey intensively used in forest product industry. The improved characteristics of heat-treated timber of Uludağ fir wood will offer the timber product industry many potential interesting opportunities. One of the endemic wood species in Turkey, Uludağ Fir having 30–40 m length, is an important industrial usage [1].

Many studies have been done in order to improve the properties of wood. The methods brought out based on the result of these studies are commonly named "wood modification methods". Heat treatment is a wood modification method too. The aim of heat treatment is to decrease swelling–shrinkage of wood, therefore, to increase its dimensional stability and biological resistance, permeability and performance of preservatives such as CCA and CCB, the quality of surface treatments and additionally to decrease equilibrium moisture content [2].

The recent industrial-scale heat treatment process of wood has been developed in the Technical Research Centre of Finland (VTT) in the early 1990s. Recent efforts on thermal treatment of wood have led to the development of several treatment processes previously or presently introduced to the European market. This has resulted in the development of Thermowood (Stellac) in Finland (Viitaniemi et al., 1994), Torrefaction (Perdure) in France (Weiland and Guyonnet, 1997) and PLATO®-wood in the Netherlands [3].

In the previous studies, it was exhibited that shrinkage–swelling, strength, hardness and density of wood decreases while its dimensional stability increases with heat treatment [2].

In many studies, the changes on dimensional stability were investigated for many trees such as beech, poplar, oak, eucalyptus, alder, maple, spruce, birch, and Scots pine with the heat treatment applied at 100–230 °C and 2–48 h [2].

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*Tel.: +90 380 5413723/143; fax: +90 380 5413778.
E-mail address: suleymankorkut@hotmail.com.

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The extent of the change in wood properties during the heat treatment depends on the method of thermal modification, the wood species and its characteristic properties, the initial moisture content of wood, the surrounding atmosphere, treatment time and temperature. Temperature has greater influence on many properties than time. Treatment at lower temperatures for longer time periods does not bring corresponding properties. Temperatures over 150 °C alter the physical and chemical properties of wood permanently. At the same time the strength properties start to weaken [4,5]. The higher the treatment temperature, the better the wood's biological durability. However, at the same time the wood's mechanical properties are more weakened. The wood becomes more brittle and bending and tension strength decreases by 10–30%. So, the use of heat-treated wood in load-bearing constructions is restricted [6].

Stamm and Hansen (1937) [7] by applying heat treatment to dried wood and Tiemann (1920) [8] by drying in high temperature, determined a decrease in hygroscopicity of wood material. In the other studies, on heat treatment, weight loss was found in wood material with increasing of temperature and time. In the study on Spruce (*Picea abies*) wood applied heat treatment during 24 h, weight loss was also found 0.8% and 15.5% at 120 and 200 °C, respectively [9].

Hardness and strength of wood decrease when heated and increases when cooled. This effect is exactly achieved with the treatment when applied for a long time [2].

The least affected property is modulus of elasticity while the most affected strengths are impact and static bending strength [10–13].

Heat-treated wood has been considered as an ecological alternative to impregnated wood materials, and it can also be used for several purposes, e.g. for garden, kitchen and sauna furniture, floors, ceilings, inner and outer bricks, doors and windows [13].

The aim of this study is to examine the effect of heat treatment on some mechanical properties in fir (*A. bornmuellerinana* Mattf.) wood, having high industrial potential and large plantations in Turkey. This study is specific as *A. bornmuellerinana* Mattf. is not studied regarding thermal treatment, temperature and time.

2. Materials and methods

Uludağ Fir logs (minimum diameter 40–50 cm) were obtained from Aladağ-Bolu, Turkey. Lumber from the logs was prepared in the sawmill of Forestry Faculty, Istanbul University, Turkey [14]. Fir lumber was planed with a knife angle of 45° and then small clear specimens were cut for compression strength parallel to grain (2 × 2 × 3 cm), bending strength (2 × 2 × 36 cm), modulus of elasticity in bending (2 × 2 × 36 cm), janka-hardness (5 × 5 × 5 cm), impact bending strength (2 × 2 × 30 cm) and tension strength perpendicular to grain (2 × 3 × 7 cm) [15].

Total of five wood samples having breast diameter ($d_{1.30\,\mathrm{m}}$) of 40–50 cm were taken from Bolu Forest Enterprises. The samples taken from the forest area have an altitude of 1540 m and the slope of the area was 38%.

After heat treatment, treated and untreated samples were conditioned to 12% moisture contents (MC) in a conditioning room at 20 ± 2 °C and 65% (±5) relative humidity (RH). The number of specimens taken from each log was nearly equal. After heat treatment applications had been made in three different temperatures (120–150–180 °C) and three durations (2–6–10 h) in a small heating unit controlled with ±1 °C sensitively under atmospheric pressure, tests of compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain were carried out based on Turkish Standards (TSE).

Compression strength parallel to grain (TS 2595) [16], bending strength (TS 2474) [17], modulus of elasticity in bending (TS 2478) [18], janka-hardness (TS 2479) [19], impact bending strength (TS 2477) [20] and tension strength perpendicular to grain (TS 2476) [21] measurements were accomplished for treated and untreated samples.

After strength test, the moisture content of samples were measured and strength values were transformed to 12% MC.

For all parameters, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test.

3. Results and discussion

Table 1 shows the results of compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain in different treatment temperature and times for all groups according to the averages all the parameters decreased with temperature and time increasing. Not only in the averages but also in ANOVA and Duncan's multiple range tests, changes were significant (Table 1).

Heating at 120, 150 and 180 °C for 2, 6 and 10 h, the diminutions in strengths were extended with increasing temperature and duration of heating (Table 2). A dramatic diminution was observed above temperatures of about 180 °C. Similar results were reported by the other researchers [22]. Vital et al. [23] reported a study of compression parallel to grain in *Eucalyptus saligna* wood samples heated to 100–155 ° for 10–160 h and they found that the compression strength values generally deteriorated with increase in temperature or exposure time .

The lowest compression strengths values were obtained for samples treated at 180 ° for 10 h (25.842 N/mm^2). The

Table 1
Relationship between heat treatment based on treatment times and compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain[a]

Heat treatment (°C)	Time (h)	Unit	Compression strength (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity in bending (N/mm^2)	Janka hardness			Impact bending strength (J/cm^2)	Tension strength perpendicular to grain (N/mm^2)
						Cross-section (N/mm^2)	Radial (N/mm^2)	Tangential (N/mm^2)		
None		Avg.	36.613 A	85.642 A	1064.829 A	41.706 A	22.576 A	24.237 A	4.836 A	2.064 A
		±s	5.869	17.678	169.538	7.155	4.264	4.184	0.984	0.222
		s^2	34.453	312.526	28743.44	51.197	18.185	17.511	0.969	0.049
		V	16.031	20.642	15.921	17.156	18.888	17.265	20.355	10.784
		N	30	30	30	30	30	30	30	30
	2	Avg.	34.197 BCDEFGHI	84.562 A	830.043 BC	41.402 AB	21.563 A	22.974 ABCD	4.577 AB	1.820 BCDEFGH
		±s	4.924	18.839	151.636	7.027	4.067	5.495	1.292	0.527
		s^2	24.254	354.918	22993.53	49.385	16.542	30.201	1.67	0.277
120		V	14.401	22.278	18.268	16.973	18.861	23.92	28.237	28.957
		N	30	30	30	30	30	30	30	30
	6	Avg.	34.053 CDEFGHI	79.479 ABC	787.162 CDEF	41.028 AB	19.448 BCDEFGH	22.815 ABCDE	4.517 AB	1.803 CDEFGH
		±s	6.441	18.405	100.562	7.335	2.952	4.437	1.315	0.488
		s^2	41.487	338.759	10112.9	53.805	8.719	19.688	1.73	0.238
		V	18.914	23.157	12.775	17.878	15.183	19.448	29.114	27.075
		N	30	30	30	30	30	30	30	30
	10	Avg.	33.784 DEFGHI	77.915 ABCD	741.718 DEFGHI	40.386 AB	19.280 CDEFGH	22.619 ABCDEF	4.282 AB	1.789 DEFGH
		±s	3.8	15.223	138.982	6.038	3.833	3.225	1.302	0.432
		s^2	14.445	231.756	19316	36.461	14.691	10.403	1.696	0.186
		V	11.249	19.538	18.737	14.951	19.88	14.259	30.408	24.148
		N	30	30	30	30	30	30	30	30
I	2	Avg.	33.500 EFGHI	77.481 ABCD	722.803 EFGHI	40.020 AB	18.859 DEFGH	21.974 ABCDEF	4.271 AB	1.783 EFGH
		±s	3.63	19.188	167.647	5.149	2.552	4.282	1.236	0.489
		s^2	13.177	368.192	28105.57	26.519	6.517	18.34	1.529	0.239
		V	10.835	24.765	23.194	12.867	13.536	19.488	28.952	27.434
150		N	30	30	30	30	30	30	30	30
	6	Avg.	33.103 FGHI	75.734 ABCD	720.375 FGHI	39.341 AB	18.855 EFGHI	21.462 BCDEF	4.253 AB	1.760 FGH
		±s	3.055	20.602	186.099	4.94	4.273	2.898	1.211	0.482
		s^2	9.333	424.472	34632.84	24.405	18.259	8.4	1.466	0.232
		V	9.229	27.203	25.833	12.557	22.662	13.504	28.472	27.405
		N	30	30	30	30	30	30	30	30
	10	Avg.	32.980 GHI	72.904 BCD	687.168 GHIJ	38.140 AB	18.220 FGHI	21.365 CDEF	4.218 AB	1.682 GHIJ
		±s	4.235	17.43	124.266	5.262	3.132	4.15	1.111	0.416
		s^2	17.94	303.822	15442.04	27.688	9.812	17.228	1.236	0.173
		V	12.842	23.908	18.083	13.796	17.192	19.427	26.356	24.764
		N	30	30	30	30	30	30	30	30

	2	Avg.	32.839 HI	71.551 CD	686.893 HIJ	37.856 B	18.062 GHI	20.929 DEF	4.073 B	1.615 HIJ
		±s	4.184	17.81	140.911	6.655	3.047	3.794	0.892	0.327
		s^2	17.506	317.23	19856.12	44.299	9.289	14.396	0.795	0.106
		V	12.74	24.892	20.514	17.581	16.874	18.128	21.902	20.239
180		N	30	30	30	30	30	30	30	30
	6	Avg.	32.791 I	68.478 DE	667.263 IJ	34.033 CD	17.926 HI	20.569 EF	3.384 CD	1.511 IJ
		±s	2.52	21.869	115.578	5.969	3.244	4.363	0.921	0.37
		s^2	6.355	478.29	13358.32	35.635	10.524	19.04	0.849	0.137
		V	7.687	31.936	17.321	17.54	18.097	21.213	27.241	24.507
		N	30	30	30	30	30	30	30	30
	10	Avg.	25.842 J	60.565 E	637.962 J	32.35 D	17.321 I	20.311 F	2.938 D	1.483 J
		±s	2.647	8.986	99.328	4.595	2.475	2.753	0.444	0.365
		s^2	7.006	80.765	9866.1	21.114	6.128	7.583	0.197	0.133
		V	10.242	14.838	15.569	14.204	14.292	13.558	15.137	24.658
		N	30	30	30	30	30	30	30	30

Avg = average; ±s = standard deviation; s^2 = variance.
V = coefficient of variation. N = number of samples used in each test.
Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test at $P<0{:}05$. Comparisons were done between the each control and its test.

Table 2
Decreasings based on temperature and times in heat treatment

Heat treatment (°C)	Time (h)	Compression strength (%)	Bending strength (%)	Modulus of elasticity in bending (%)	Janka hardness			Impact bending strength (%)	Tension strength perpendicular to grain (%)
					Cross-section (%)	Radial (%)	Tangential (%)		
120	2	6.59	1.26	22.04	0.72	4.48	5.21	5.35	11.82
	6	6.99	7.19	26.07	1.62	13.85	5.86	6.59	12.64
	10	7.72	9.02	30.34	3.16	14.59	6.67	11.45	13.32
150	2	8.50	9.52	32.12	4.04	16.46	9.33	11.68	13.61
	6	9.58	11.56	32.34	5.67	16.48	11.44	12.05	14.72
	10	9.92	14.87	35.46	8.55	19.29	11.84	12.77	18.50
180	2	10.30	16.45	35.49	9.23	19.99	13.64	15.77	21.75
	6	10.43	20.04	37.33	18.39	20.59	15.13	30.02	26.79
	10	29.41	29.28	40.08	22.43	23.27	16.19	39.24	28.14

compression strength loss at 180 ° for 10 h were observed as 29.41% (Table 2).

Yildiz [22] obtained similar compression strength results for beech wood in the same treatment time and temperature. In this case, it can be said that temperature might have greater influence on strength properties than time.

The diminutions in the strength properties were related to the rate of thermal degradation and losses of substance after heat treatments. The decrease in strength is mainly due to the depolymerization reactions of wood polymers [24]. The primary reason for the strengths loss is the degradation of hemicelluloses, which are less stable to heat than cellulose and lignin. Changes in or loss of hemicelluloses play key roles in the strength properties of wood heated at high temperatures [25].

It is known that the weight of wood material and its strength decreases when heated.

According to the results obtained in this study all properties decreased by increasing temperature and duration and this change was maximum in 180 °C and 10 h Table 2 shows the decreases reached with increasing thermal treatment conditions.

Studies on both spruce (*Picea orientalis* L.) and beech (*Fagus orientalis* L.) heated at 200 °C for 6 h resulted in a 36% decrease in compression strength. On the other hand, a slight increase in compression strength was observed at 130 °C for 6 h. At the same study, it was emphasized that compression strength was affected less with temperature increase compared to the other strength properties [22].

The highest decrease in modulus of elasticity for spruce was found to be 41.5% at 200 °C for 6 h. On the other hand, a slight increase (8.4%) in modulus of elasticity was observed at 130 °C for 10 h treated samples. For beech, heat treatment at 200 °C for 10 h resulted in an increase in modulus of elasticity (39%). The lowest bending strengths for beech and spruce were observed when the wood samples were treated at 200 °C for both 6 and 10 h. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce for 6 and 10 h treatment time at 200 °C [22].

Most decrease in hardness values were observed when beech and spruce samples were treated at 180 °C for 10 h. For beech samples, 25.9%, 45.1%, and 41.8% decrease in hardness was observed for cross section, radial direction and tangential direction, respectively. For spruce 19.7%, 43.0% and 42.5% decrease was observed for cross section, radial direction and tangential direction, respectively [22].

Yildiz [22] found that the elasticity modulus and compression strength values of same wood samples decreased by thermal modification, however, the water repellence efficiency of the same wood samples (spruce and beech) were increased heated in the same temperature and duration.

In a study on the effect of heat treatment, for pine sapwood heated at 110, 130, 150 and 180 °C and 40 in thick it was found that compression strength decreased by % 5 [26]. In another study, ıt was determined that for Eucalyptus (*E. saligna*) wood compression strength parallel to grain decreased at 110–155 °C and 10–160 h [23].

These results can be explained with material loses in cell lumen and hemicellulos degradation due to applied height temperature [27,28].

With this study on fir (*A. bornmuellerinana* Mattf.) wood untransfered to wood products industry because of its negative properties, by heat treatment, it was found that compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain will decrease.

The changes in the mechanical and physical properties of heated wood are generally attributed to the thermal degradation of wood substance [5].

Fig. 1 shows the effect of heat treatment on wood strength properties at 120, 150 and 180 °C for 2, 6, and 10 h.

We know that today, it can be said that strength loses can be limited through advanced heat treatment techniques

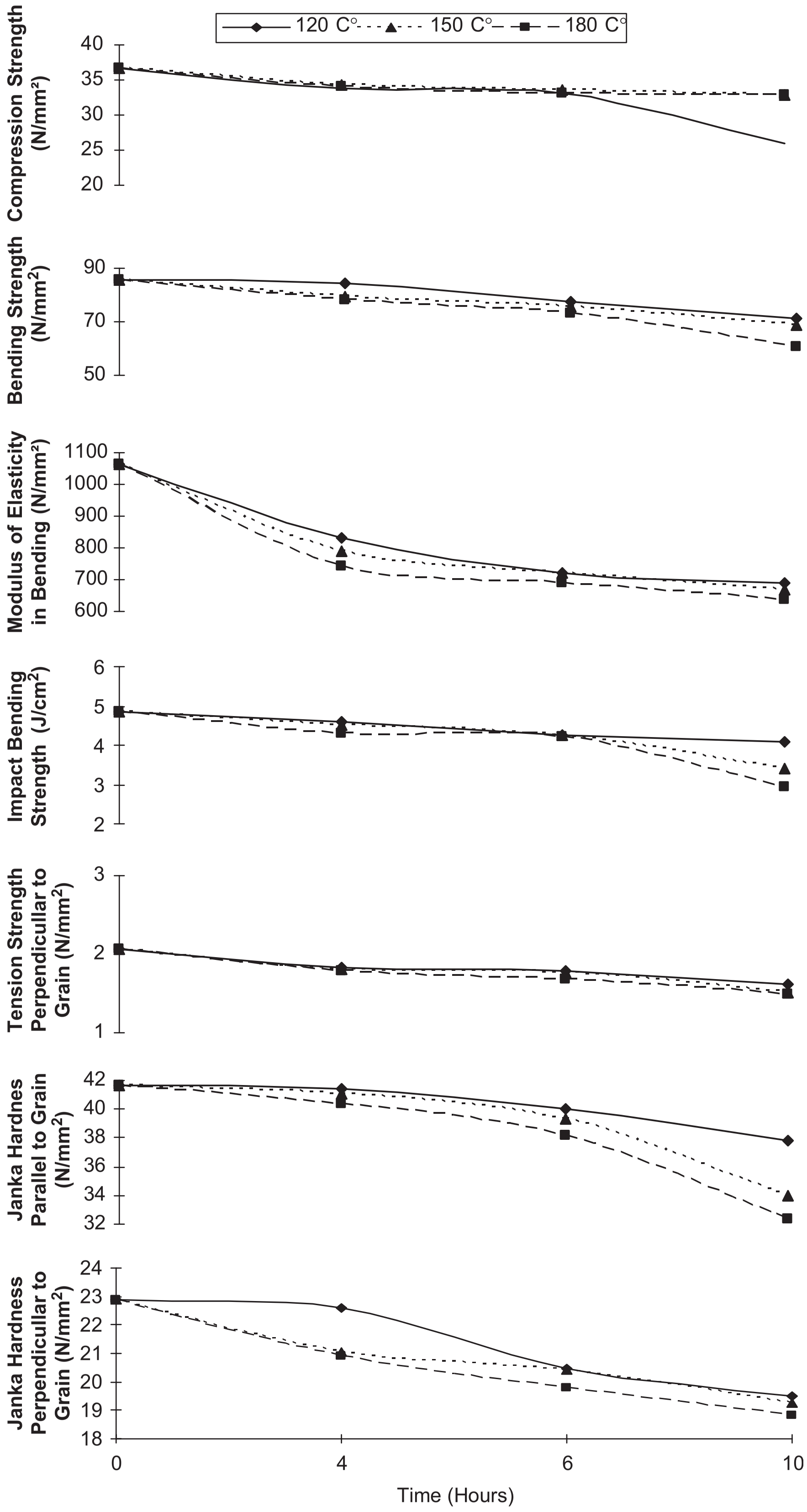

Fig. 1. The effect of heat treatment on strength properties of wood.

[2]. So, this tree species can be utilized using proper heat treatment techniques without any loses in strength values in areas which are important the working and stability. Heat-treated wood material is very suitable for coating applications and it can also be used for several purposes, e.g. for garden, musical instruments, kitchen furniture, paneling, parquets, sauna, doors and windows.

Improved wood properties such as shrinkage and swelling depending on equivalent moisture content thought to be a new approach for lumber utilization places. Therefore, heat treatment may improve these properties of wood, having no industrial usage.

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